Technical Note N-1229

HYDRAULIC TOOLS AND EQUIPMENT FOR UNDERWATER SALVAGE

By

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ABSTRACT

Extending the U.S. Navy's underwater salvage capability will require improved diver-operated tools and equipment. NCEL (Naval Civil Engineering Laboratory) is conducting a program to develop hydraulic hardware for future underwater salvage operations. Commercially available hydraulic pumps, rigging, load handling and cutting equipment have been evaluated at NCEL to determine characteristic diver performance and mechanical suitability for underwater operation. Manually operated hydraulic pumps were modified and pumped against a load cell to determine reasonable levels of diver exertion. Tests have shown that divers can be utilized as prime movers for small jobs and that some conventional surface hydraulic equipment can be used underwater for reasonable periods of time with a minimum of additional maintenance. Surface hydraulic equipment suitable for underwater operation includes manual pumps, rams, cylinders and several cutters. However, innovative new equipment is urgently required for underwater salvage, particularly for load handling.

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INTRODUCTION

Under the sponsorship of the U. S. Navy Supervisor of Salvage, the Naval Civil Engineering Laboratory is developing hydraulic tools and equipment for LOSS (Large Object Salvage System) type operations. The purpose of this program is to (1) develop hydraulic salvage equipment for divers; and (2) develop hydraulic salvage equipment suitable for operation from submersibles to depths of 20,000 feet.

The Naval Civil Engineering Laboratory's hydraulic salvage tool program started with a definition of the work functions that will be required in future salvage.* These work functions include rigging and load handling, bolting, and cutting. Subsequently, commercially available hydraulic tools and equipment for rigging, load handling and cutting were acquired and tested by Navy divers (hydraulic impact wrenches have been previously evaluated by NCEL**). The testing was performed during December 1970 and from January to March 1971. The results of these underwater tests are evaluated and the limitations of the commercial hydraulic tools used underwater are discussed.

BACKGROUND

It is well documented in the diving literature that the diver's ability to perform useful work underwater is much less than his ability to do work on the surface. Therefore, it is very desirable to improve the diver's performance by providing him with effective power tools. Previous work at NCEL has established the superiority of hydraulic power tools for most underwater operations.

The Navy is presently extending its salvage capability into the deep ocean. Improved hydraulic tools and equipment are required to enable the underwater salvor to work effectively and NCEL is developing the hydraulic hardware for this mission. The development program has been designed to first evaluate the commercially available hydraulic tools and components that could be used in future salvage operations.

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* Naval Civil Engineering Laboratory. Technical Note N-1145; Underwater Work Functions Required in Salvage, by G. L. Liffick. Port Hueneme, California, February 1971.

**Naval Civil Engineering Laboratory. Technical Report R-729: Technical Evaluation of Diver Held Power Tools, by S. A. Black and F. B. Barrett. Port Hueneme, California, June 1971.

The data and experience gained with the commercial hydraulic salvage equipment will then be used to design and fabricate improved hydraulic salvage equipment for divers, as well as for operation from submersibles. The high cost of developing a new hydraulic tool makes it imperative that the requirement for the tool be firmly established and that valid design data be available. Satisfactory design data can usually be generated with underwater tests of either modified commercially available tools or bread-board type tools built from existing components. This report is one of three that will present underwater test results and evaluate commercially available and bread-board type hydraulic salvage equipment. Additional reports are planned on hydraulic power sources and abrasive cutting. Open center hydraulic tools are preferred for underwater operations because the hydraulic fluid circulates through the hoses at all times reducing the undesirable increase in fluid viscosity when the hoses are in cold water. Hydraulic power sources driven by diesel engines or electric motors are available to operate open center hydraulic tools and equipment. However, most of the commercially available hydraulic cutting, rigging and load handling equipment utilize single acting (rams) or double acting hydraulic cylinders which are not an open center configuration but require small volumes (<30 in^3) of fluid at high pressures (2000 to 6000 psi). Simple diver powered pumps were evaluated by NCEL as an alternative to providing a separate, complex and expensive hydraulic power source for the salvage equipment based on hydraulic rams and cylinders.

TEST FACILITIES AND EQUIPMENT

The hydraulic salvage equipment selected for testing was operated by the Navy personnel assigned to NCEL's Diving Locker and by NCEL diving engineers, including the senior author. The hydraulic tools and equipment were used both in the diving tank at the NCEL Diving Locker and in 60 feet of water at Anacapa Island off the Southern California coast. Most of the diving was done in wet suits with either a Navy shallow water mask or the Kirby-Morgan band mask. This diving equipment was used because of its similarity to the diving dress worn by divers working out of a bell system (e.g., Mark I DDS). Some tool evaluation diving was also done in deep sea dress (Mark V) and with scuba gear.

The Navy T6B pontoon in Figures 1 and 2 was modified for use as a test stand. Attached to the sides of the pontoon were lifting brackets, frames for holding wire rope and bar stock, frames for tensioning wire rope slings, a hydraulic hacksaw track, and a load cell. The load cell is shown schematically in Figure 3. It was welded to the top of the pontoon and provided an essentially constant ($<10\%$ variation) load throughout a 10-inch stroke. This load cell was used for the hydraulic ram and pull cylinder tests. The force required to move the load cell cylinder rod was variable by changing the air pressure in the storage bottles. The maximum working load was 4-1/2 tons (9000 pounds) because of load cell frame deflection.

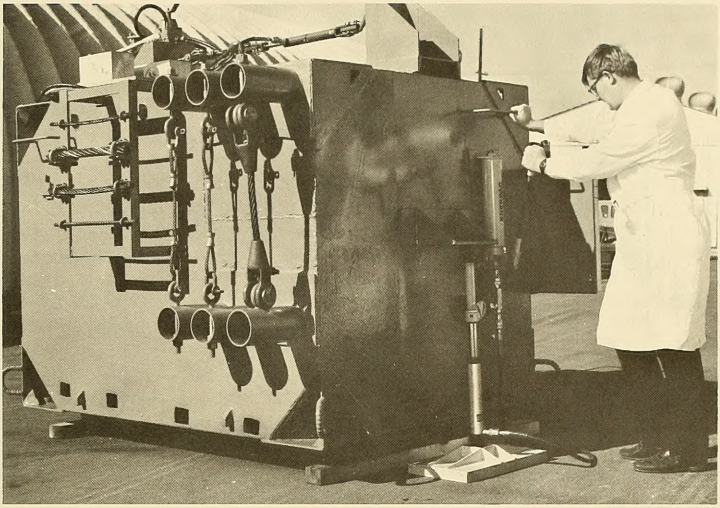

Figure 1. Test Stand

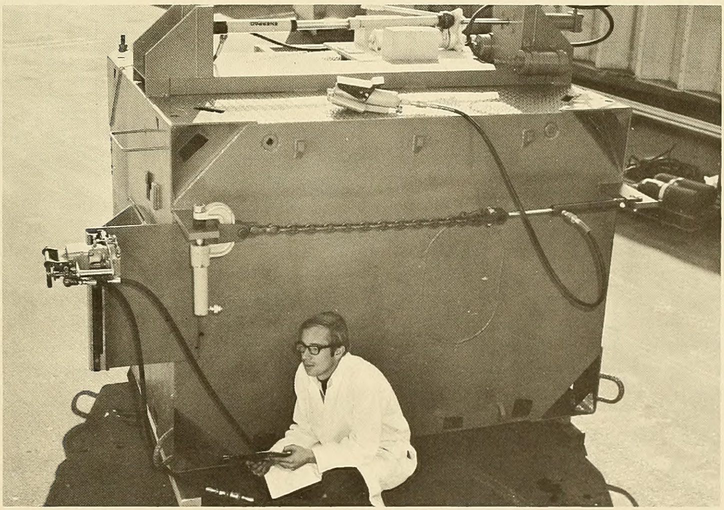

Figure 2. Test Stand

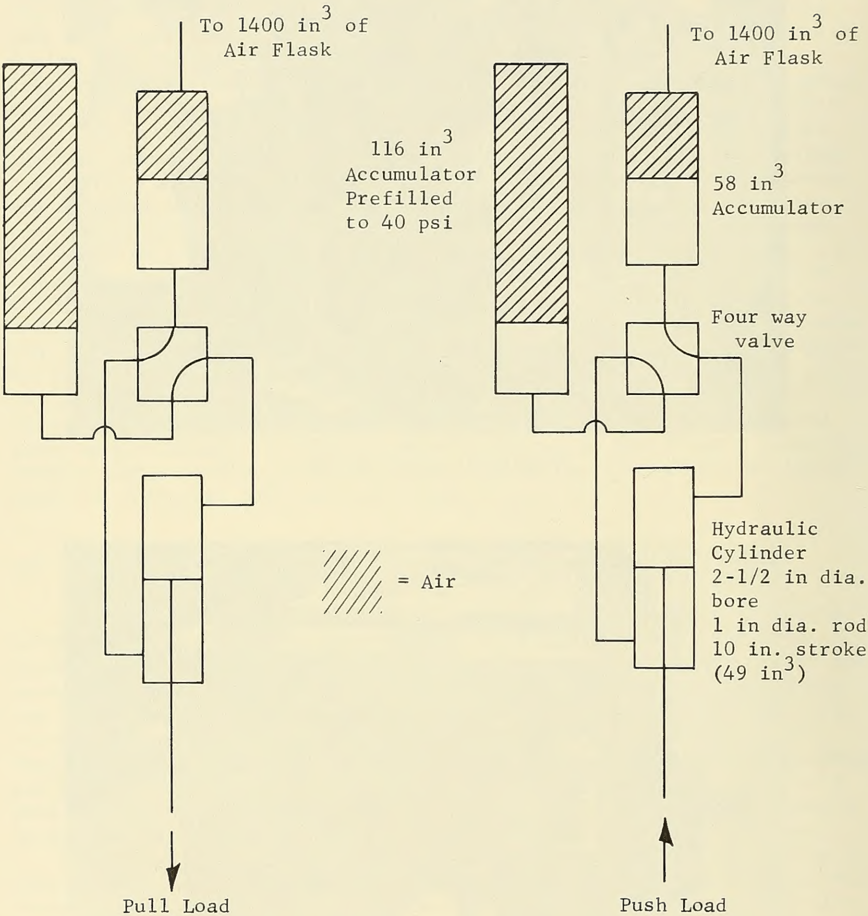

Figure 3. Load Cell Schematic

In addition to providing a base for test fixtures, the entire test stand was used as a jacking and pulling load on the ocean bottom at Anacapa Island.

PRESENTATION OF THE TEST RESULTS AND EVALUATIONS

A large number of tools and equipment were tested in the hydraulic tools program. The evaluation of these tests is divided into two groups. The first group includes the tests of tools and equipment that were powered by the divers themselves. The second test grouping is the open center equipment that was supplied with hydraulic power from a diesel-driven hydraulic power source. The tools and equipment are discussed individually with the following format:

Description of the tool/equipment
Purpose of the tool/equipment
Test objective and description
Test data
Human factors analysis of the tool/equipment
Mechanical analysis of the tool/equipment

DIVER-POWERED EQUIPMENT

Hydraulic Pumps

All the diver-powered hydraulic pumps tested were automatic two-speed commercial pumps with a low pressure (<350 psi) piston displacement of 0.9940 cubic inches and a high pressure (<10,000 psi) piston displacement of 0.1503 cubic inches. The pump alone weighed 27 pounds in air and 18 pounds in water. The hydraulic pumps were modified for operation underwater based on the type of diving equipment used.

The pump shown in Figures 4 and 5 was mounted on a piece of 3/4-inch plywood with a handle on one end and a 20-pound weight on the other end. The pump operates on the down or push stroke and was designed for operation by divers using scuba equipment and Navy shallow water gear. The other hydraulic pump also designed for scuba and shallow water gear is shown in Figures 6 and 7. The handle pivot point on this pump was reversed so that pumping occurred on the up or pull stroke. The third pump, shown in Figures 8 and 9, was modified so that a diver in the Navy's Mark V deep sea dress could stand on the base and operate the pump with the extended handle.

This type of hydraulic pump (without modification) normally is used to operate jacks, wire rope cutters, and pipe benders in industrial facilities and on construction projects. The purpose of testing these pumps underwater was to determine if they could be used by salvage divers to generate quantities of high pressure hydraulic fluid to accomplish useful work. It is not desirable to utilize the diver as a prime mover on large or repetitive-type tasks, but the low cost and availability of

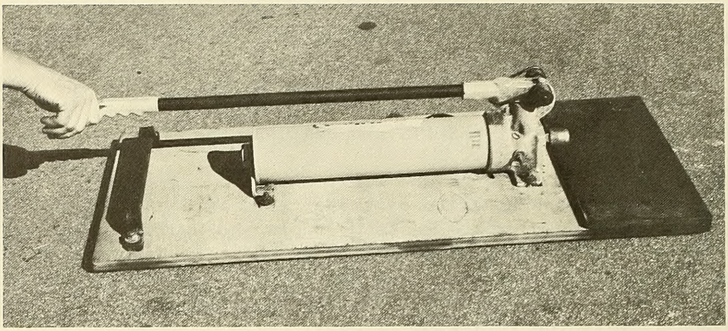

Figure 4. Push-Stroke Hydraulic Pump

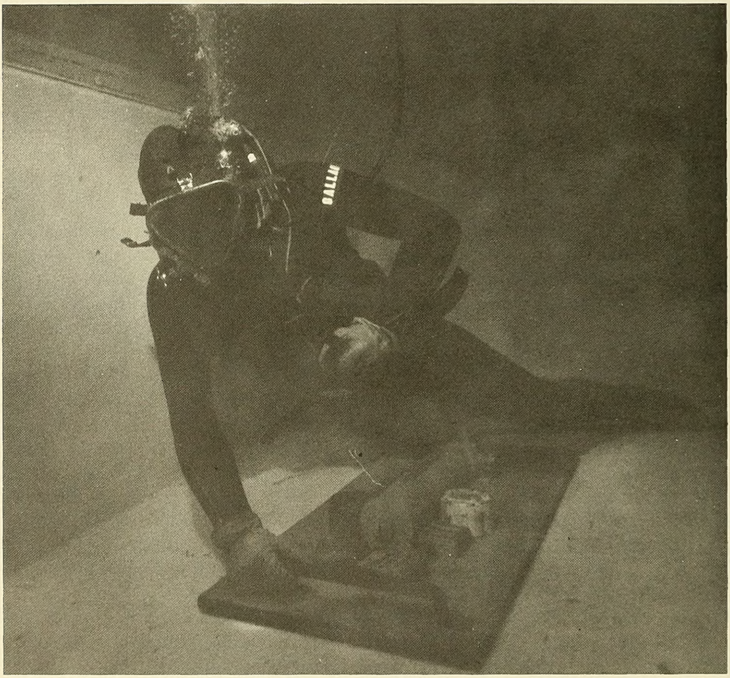

Figure 5. Diver Operating Push-Stroke Hydraulic Pump

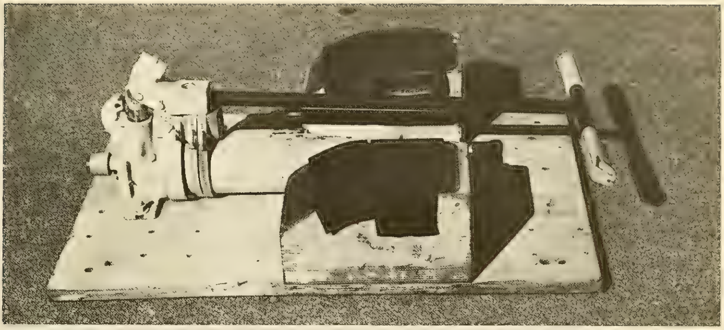

Figure 6. Pull-Stroke Hydraulic Pump

Figure 7. Diver Operating Pull-Stroke Pump

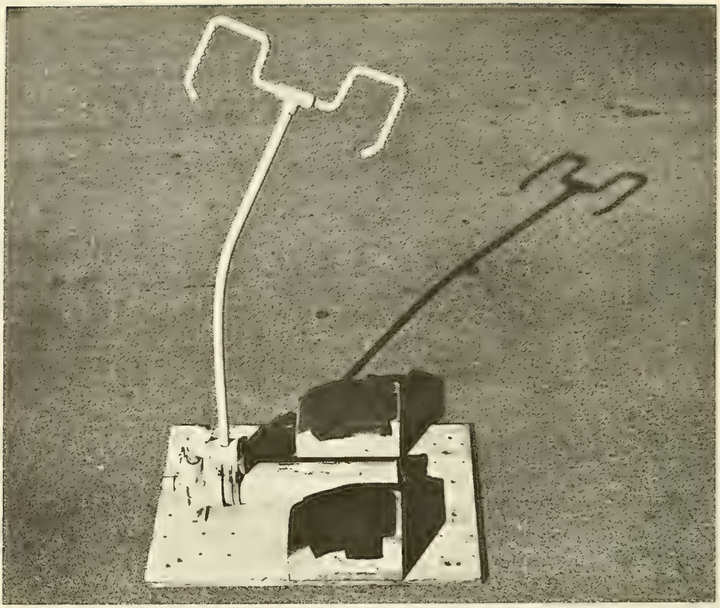

Figure 8. Deep Sea Dress Hydraulic Pump

Figure 9. Diver Operating Deep Sea Dress Pump

manually operated hydraulic pumps makes them desirable for small jobs.

The underwater tests were designed to determine the ability of Navy divers to operate the pumps in different types of diving gear and to determine the susceptibility of this type of pump to salt water corrosion. For the diver performance tests a hydraulic ram was repeatedly extended against the load cell.

The forces required to operate these pumps (see Figure 10) depended on the handle modifications. The forces in Figure 10 were applied normal to the handle at the location where the diver usually would hold it. Divers found it difficult to operate the hydraulic pumps at the higher pressures shown for each pump. It was not possible to find the handle forces required for hydraulic pressures above 4000 psi because of excessive load cell deflection. The pull stroke pump was adequate for diver operation to hydraulic pressures of 4000 psi. The push stroke pump's usefulness was limited to 1000 psi, and the pump used with the deep sea dress was usable but not recommended for diving operations.

The mean times for the diver to pump 20 cubic inches (one ram extension) of hydraulic fluid at pressures ranging from 450 to 3600 psi are shown in Table I. Each cubic inch of fluid pumped required 6.6 full strokes of the pump handle. These tests were performed in the NCEL Diving Locker Tank with good visibility and water temperatures of 60 to 65°F. The mean times are the average of four to six repetitions by four different divers. Each diver was in the water for 15 to 30 minutes.

Table I. Summary of Diver Operated Hydraulic Pump Tests

Pump and Diving Dress	Hydraulic Pressure (psi)	Mean Time to Pump 20 cu in of Fluid (Min)	Range of Times (Min)
Pull stroke pump w/wet suit and Kirby-Morgan Band Mask	450	-	-
	900	3.2	2.5 - 3.6
	1800	3.6	2.9 - 4.3
	2700	3.8	3.5 - 4.1
	3600	4.0	2.9 - 4.5
Push stroke pump w/wet suit and Kirby-Morgan Band Mask	450	2.9	2.3 - 3.3
	900	3.0	2.7 - 3.6
	1800	-	-
	2700	-	-
	3600	-	-
Deep Sea Dress Pump and Diving Gear	450	-	-
	900	-	-
	1800	6.2	4.6 - 6.8
	2700	7.1	4.1 - 9.5
	3600	7.1	4.6 - 9.5

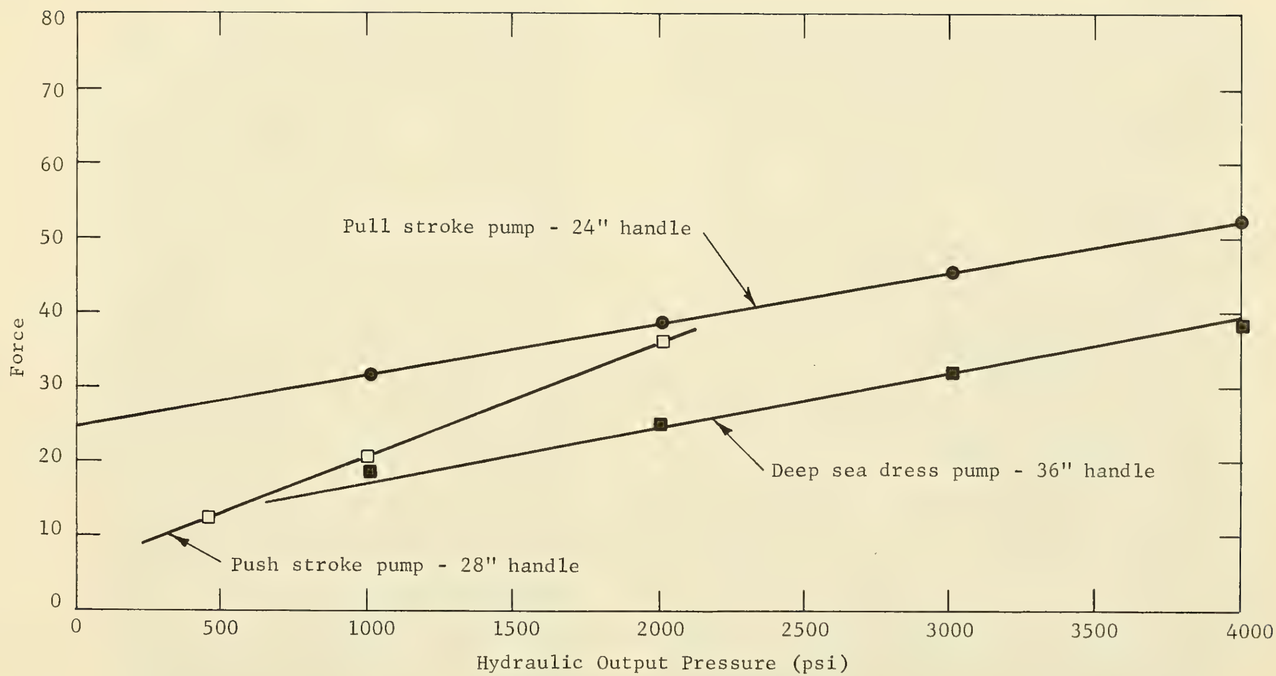

Figure 10. Required pump handle forces

For underwater operations in scuba or shallow water diving gear, the push pump requires only mounting on a suitable base. However, the application of this pump is limited because the maximum pressure that the diver can develop is approximately 1000 psig. The pump is very fatiguing to use because almost all of the developed thrust must be generated by the diver's pumping arm. Most of the test divers were observed to change arms quite often to reduce fatigue.

The pull stroke pump has the advantage of developing a fourfold larger pressure of 4000 psi with scuba or shallow water gear. The divers are able to more effectively utilize their muscular strength. The pull pump allows the diver to use his leg and back muscles for higher hydraulic pressures or when his arms become fatigued. It is also possible for shorter divers to operate the pump in the standing position in contrast to the usual kneeling position as shown in Figure 7. Here again, the back and leg muscles may be used effectively. The principal disadvantage is that extensive handle modifications are required to convert the pump to a pull stroke, and more weight or attachment force is required to hold the pump base down against the deck (50 pounds vs 20 pounds for the push stroke pump).

The following features are recommended for future pull pumps:

1. A pump handle that is readily adjustable in length. (It is faster and results in less total expenditure of energy to use a shorter handle for lighter loads or for use by divers of exceptional strength.)
2. Padded knee rests with concave upper surfaces designed to fit the contour of the diver's knees.
3. A metal base plate for the pull pump which permits stud gun or bolting attachment.

The pump used with the standard Navy deep sea dress (Figures 8 and 9) is more difficult to use than the other configurations. The diving helmet and breast plate are heavy and result in much wasted energy when the diver's work results in large body movements. Also, the diver's air hose and valve are in the way when the handle is thrust right and left in the standing position. Some commercially available hard hat gear reduces these disadvantages. The hat and breast plate of this gear are much lighter, and the valve has been moved up on the helmet where it is accessible but not in the diver's way. Hard hat gear does have the distinct advantage of providing the diver with much better buoyancy control than light weight or scuba gear. This permits the diver to safely wear much more weight which is often a distinct advantage in using both manual and power driven tools.

The diver operated hydraulic pumps all have a sealed hydraulic fluid reservoir. As the hydraulic fluid is removed from the reservoir the internal pressure drops below atmospheric pressure. This is an undesirable feature for underwater operation. It is preferable to compensate the fluid reservoir to ambient pressure in order to reduce the salt water leakage into the reservoir around the pump piston. The hydraulic pump reservoirs were not pressure compensated for the NCEL tests in order

to determine how serious the leakage would be at shallow depths.

At the start of the salvage tool tests it was not known how often the hydraulic fluid should be changed to prevent pump failures. It was decided to begin with a weekly hydraulic fluid change and increase the time between changes during the test program. Near the end of the tests the fluid was not changed for over a month. Although there were always small amounts (<3%) of water in the hydraulic fluid when it was drained from the pumps, the corrosion inhibitors in the hydraulic fluid prevented any pump corrosion. It is estimated that this type of hydraulic pump with no maintenance or pressure compensation has a minimum life of several months in shallow water when a corrosion-inhibited hydraulic fluid is used.

Hydraulic Cylinders

The two types of hydraulic cylinders tested underwater are shown in Figure 11. The top one is a double-acting cylinder which was used for pulling. The bottom one is a single-acting cylinder (ram) for pushing or jacking. Double-acting cylinders can be used in either a push or pull mode, whereas single-acting cylinders can exert a force only in one direction and are usually returned to their retracted position by an internal spring. The advantage of using rams for lifting and pushing is that the rod (piston) is much larger than a double-acting cylinder rod with the same size housing. This is important because the ram is loaded as a column and must resist lateral deflection. Both of the ram and cylinder were used with the diver-powered hydraulic pumps.

The ram shown in Figure 11 is capable of lifting loads to 10 tons. With various extensions, end connections and accessories, it is typical of the "hydraulic rescue and maintenance sets" used to move heavy equipment in industrial firms. Some typical ram and accessory combinations are shown in Figure 12. These accessories have a five ton rating. The ram and accessories are connected together with either threaded couplings or connectors that slide inside the pipe extensions and are locked in place with pins (see Figure 13).

The two purposes in testing the hydraulic rams were to (1) determine the diver's ability to select and assemble the correct accessories underwater to fit an opening; and (2) to determine the forces that the ram end connections would support without slipping on flat perpendicular and sloping surfaces.

The time required for the divers to select components from the tool box shown in Figure 14 and to assemble them with the ram to fit a 60-inch horizontal span is shown in Table II.

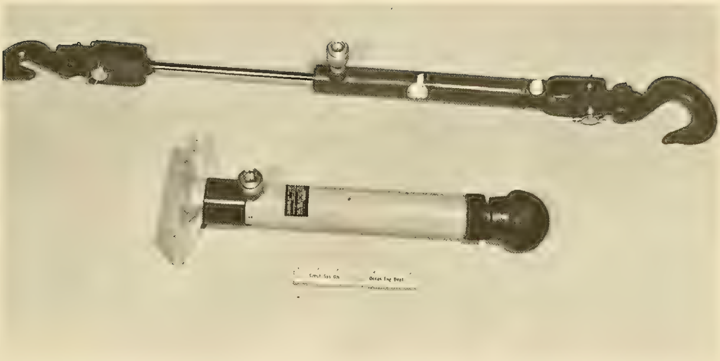

Figure 11. Hydraulic Ram (Lower) and Cylinder (Upper)

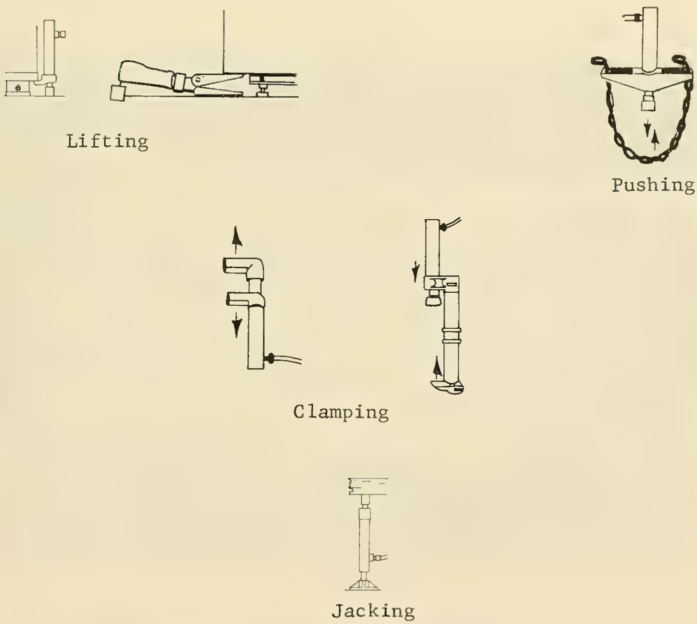

Figure 12. Typical Hydraulic Ram System

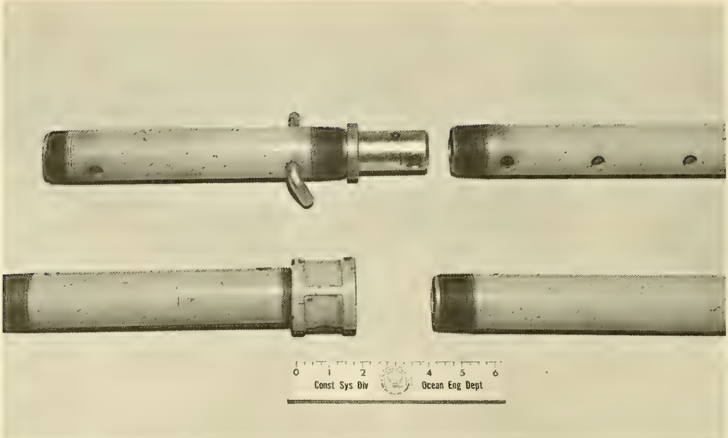

Figure 13. Ram Extension Connectors

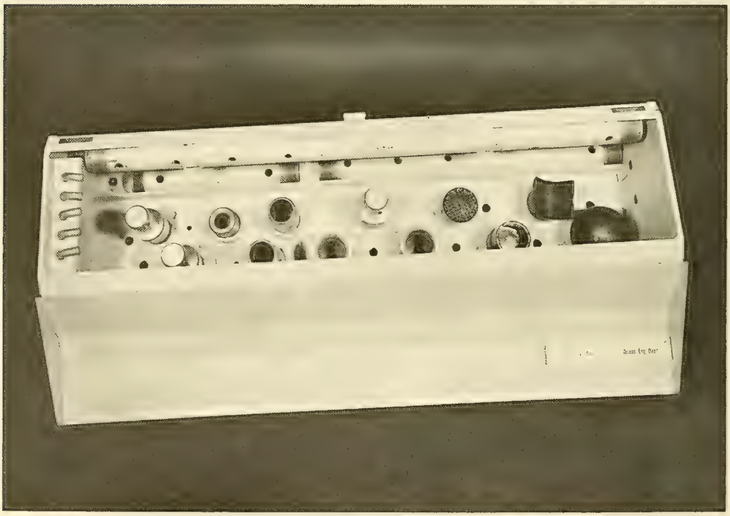

Figure 14. Ram Accessories and Tool Box

Table II. Time Required to Assemble Ram System

Threaded Connections			Pinned Joint	
Diver	Assembly Time (Min)	Inches Short of 60-Inch Span	Assembly Time (Min)	Inches Short of 60-Inch Span
1	2.5	4	3.4	2
2	1.0	4	2.1	5
3	3.7	5	7.6	6
4	2.3	5	2.9	6
Mean	2.2	4.5	4.0	4.8

The times for the divers to extend the 10-inch stroke ram against various loads are shown in Table III. These times are for ram extensions with the pull stroke hydraulic pump (Figure 6) and do not include any assembly time.

Table III. Times Required for Divers to Extend Ram

Load on Ram (Tons)	Hydraulic Pressure at Ram (psi)	Mean Time for 10" Ram Extension (Min)	Range of Extension Times (Min)
1	900	3.2	2.5 to 3.6
2	1800	3.6	2.9 to 4.3
3	2700	3.8	3.5 to 4.1
4	3600	4.0	2.9 to 4.5

The three ram end connections in Figure 15 were tested underwater to determine the maximum loads they would support without slipping. A diver placed the ram assembly between the two ends of the load cell. One end of the load cell was always vertical. The other end was varied from a parallel position to a slope of 30° from parallel (see Figure 16).

Figure 15. Ram End Connections

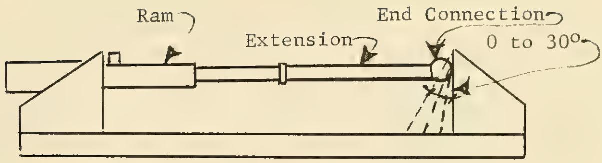

Figure 16. End connection test setup

The results of these tests are shown in Table IV. It was not possible to apply forces greater than 9000 pounds to the ram system because of excessive load cell deflection. In summary, the end connections performed well on perpendicular surfaces and surfaces with a 10° slope. The threaded connections were slightly more rigid than the pinned joints.

Table IV. Ram End Connection Tests

End Connection and Angle from Parallel Surfaces		Force @ Slippage lbs or Maximum Force Applied: Threaded Extension Connections		Pinned Joint Extension Connections	
		Trial 1	Trial 2	Trial 1	Trial 2
Serrated End	0°	9000*	9000*	9000*	9000*
(Right end in	10°	9000*	9000*	9000*	9000*
Figure 12)	20°	8775*	8100*	9000*	9000*
	30°	8100*	7825*	9000*	9000*
Rubber End	0°	9000*	9000*	9000*	9000*
(Middle in	10°	9000*	9000*	4050	4050
Figure 12)	20°	450	340	450	450
	30°	0	0	0	0
V End	0°	9000*	9000*	9000*	9000*
(Left in Fig 12)	10°	9000*	9000*	9000*	9000*
Axis of Head	20°	0	0	6750	0
Vertical	30°	0	0	0	0
V End	0°	9000*	9000*	9000*	9000*
Axis of Head	10°	9000*	9000*	9000*	9000*
Horizontal	20°	9000*	9000*	9000*	9000*
	30°	9000*	9000*	9000*	9000*

*Slippage did not occur but the load cell bent excessively requiring termination of the test at the indicated pressure.

The ram presented no particular diver handling problems. However, the threaded extensions were difficult to start. Divers typically have problems aligning threaded fittings underwater and this is compounded if there is poor visibility. The threads on the ram accessories were coated with a commercial non-seizing compound to prevent corrosion. The non-seizing compound was messy for the divers to handle but did an excellent job of preventing corrosion. The divers were able to assemble and disassemble the threaded connections by hand throughout the test program. The hand-tightened threads did not deform under the 4-1/2 ton loads, and the extensions usually could be disassembled by the divers in the water.

Several problems were encountered using the pinned connectors. The connectors had to be inserted the correct distance and rotated properly before the pin could be inserted. The pins are relatively easy to lose and hard to find in a tool box or tool bag. The pins also occasionally jammed after a heavy load had been applied and it was often impossible for the divers to disassemble the connections underwater because of bent pins and jammed inserts.

The following design changes are recommended to reduce the described problems:

1. Redesign the extensions as shown in Figure 17a. This would permit the load to be borne entirely by the shoulders of the pin connection insert. The retainer pins should be chained to the extension pipe, and the clearance between the retainer pin, the connection pin, and the extension pipe should be adequate to permit very easy insertion and removal.

2. An alternate method of extending ram length was suggested by one of the divers and is shown in Figure 17b.

All components of these extension systems must be of sufficient strength and corrosion resistance to prevent jamming from application of heavy loads or from corrosion.

The rams used as jacks are susceptible to seawater corrosion because water is drawn into the evacuated space between the piston and the housing on the return stroke (see Figure 18). During the next ram extension some of this water may leak past the pressure seal into the hydraulic fluid. This leakage can be tolerated if a corrosion-inhibited hydraulic fluid is used. However, corrosion begins if the ram is stored with salt water between the piston and the housing. The water eventually corrodes the housing so that the pressure seal leaks during extensions and the corrosion can become so severe that the piston is frozen to the housing. Corrosion can be reduced by storing the ram with the piston extended so that the housing interior is covered with hydraulic fluid. The rams at NCEL were in a satisfactory condition after the three-month test program even though they were submerged for several one-week periods. Whenever they were not being used, they were stored with the rod extended.

In addition to the ram used for jacking, double-acting hydraulic cylinders were evaluated as a method of pulling loads. The extended double-acting cylinder with hooks in Figure 11 has an overall extended

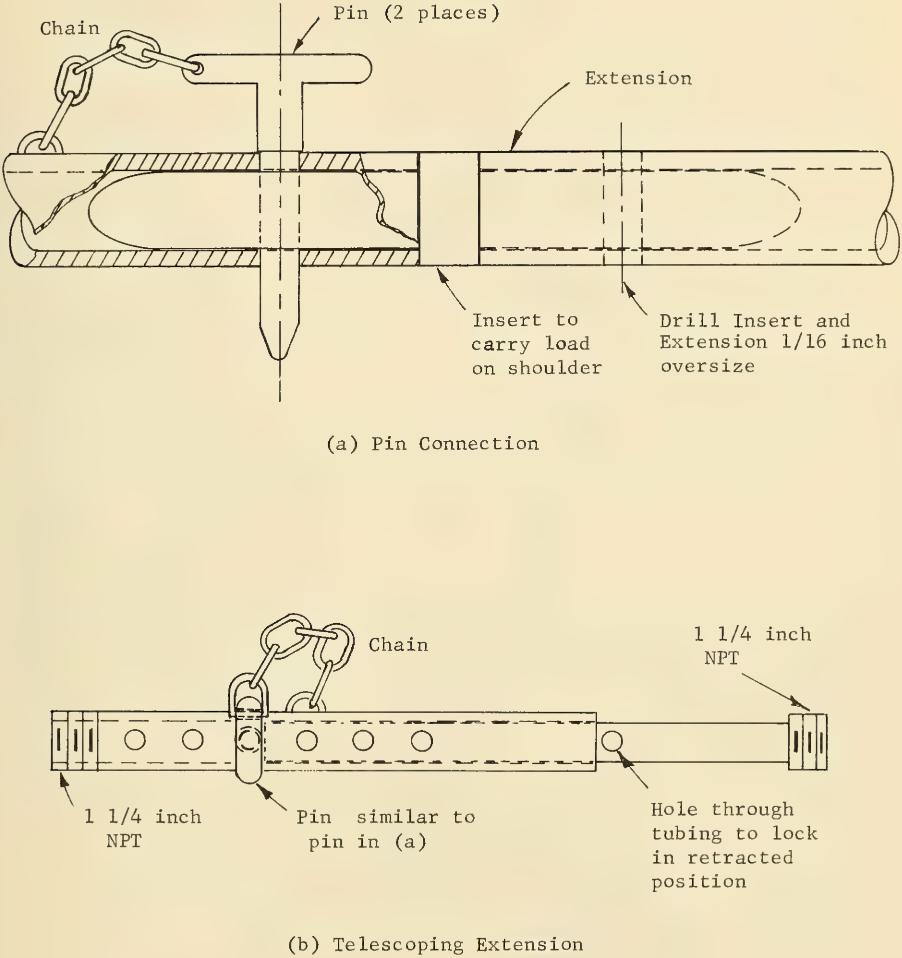

Figure 17. Improvements for a
Ram Extension System

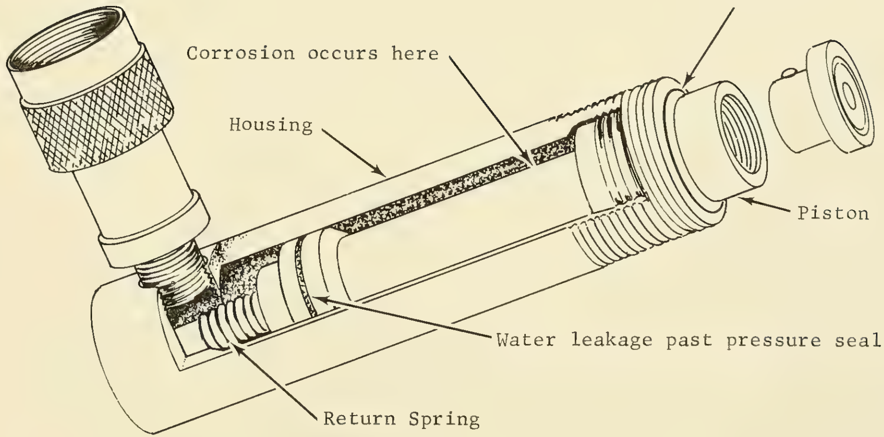

Figure 18. Hydraulic Ram

length of 46 inches and a weight in water of 15 pounds. It has a 10-inch stroke and develops a pulling force of three tons at its rated hydraulic pressure of 4500 psig. The cylinder is attached to a chain hook on one end and a slip hook on the other end. The slip hook is connected to the object to be moved and the chain hook is attached to a chain which is shackled to a solid object. By repetitively extending the cylinder rod and reattaching the chain hook to the chain, the load can be pulled along a horizontal surface. To move a load up an inclined surface, two cylinder and hook assemblies are required. The two assemblies are connected to the hydraulic pump so that one retracts when the other extends. The cylinder with the extended hook is attached to the chain and picks up the load as the retracted cylinder extends.

The purpose of testing these cylinders underwater was to determine their mechanical suitability for underwater use and establish the practicality of a diver-powered chain and hook pulling system.

Because of insufficient space it was not possible to evaluate the pulling system in the diving tank. However, several cycles of connecting and disconnecting the chain hook were performed with the load cell in the tank. The mean time for the disconnect/connect cycle was 0.9 minutes.

During the tests at Anacapa Island, the entire test stand was pulled across the bottom using one-half inch chain and the double-acting cylinder. The divers were able to move the half-inch chain easily, but they were not able to pull it tight because the other end of the chain was fastened two feet above the ocean bottom. Consequently, the test stand was pulled only two to three inches for each 10-inch stroke. This problem can be reduced by using a chain load binder or by using two cylinders as previously discussed. In these open ocean tests, it took from 0.7 to 1.5 minutes (mean 1.2 minutes) for the divers to complete a disconnect/connect cycle with the chain hook and chain. With a pulling load of three tons it took the diver using a pull-stroke hydraulic pump 2.5 minutes per 10-inch retraction. Thus, with a diver powered pump, a complete connect-pull-disconnect-extend cycle requires about 4 minutes. With good rigging loads can be moved 7 to 8 inches for each 10-inch stroke.

The double-acting hydraulic cylinder used for pulling functioned satisfactorily except for the rigging problems. Other types of pulling equipment which use cable, such as grip hoists, cable hoists or winches, are probably superior for pulling tasks which require moving the load a considerable distance. They may be operated continuously or at least to the full cable length in contrast to hydraulic cylinders which require some type of diver rigging action at the end of each stroke.

For very heavy pulling loads, hydraulic cylinders have the distinct advantage of being operable with the diver pumps. As previously explained, the pull pump is an efficient tool for diver use because arm, leg and back muscles may be utilized.

If heavy loads must be moved some distance, it would be possible to use a hydraulic cylinder and a cable hoist in line. The cable hoist could be used by the buddy diver to take up the slack in the cable after

each pull stroke (when the cylinder is returned to the extended position). This would eliminate the rerigging problem and allow an effective full stroke.

Double-acting hydraulic cylinders draw less water into the housing per stroke than rams because the pressure seal is located where the piston rod enters the housing. Unfortunately, even a modified double-acting hydraulic cylinder with an exterior wiping seal will bring a very thin film of water on piston rod into the cylinder. This unavoidable problem can usually be controlled by using a corrosion-inhibited hydraulic fluid and changing it periodically.

Hydraulic Cutters

The hydraulic wire rope cutter in Figures 19 and 20 cuts wire rope to 1-1/8-inch diameter and weighs 20 pounds in water. It can be operated by one diver because the cutting head arrangement holds the cutter on the wire rope. Slippage of the cutter down a vertical or sloping wire rope prior to cutting can be prevented by using a pair of vise grips. The cutter is connected to a diver powered hydraulic pump. The use of hydraulic hose permits operation of the pump as far as 100 feet from the cutter. This is very desirable if a wire under tension is cut.

This hydraulic cutter is sold for the production cutting of wire rope and is normally supplied with hydraulic fluid from an electrically-driven hydraulic power pack.

The purpose in testing this hydraulic cutter was to determine the performance of the cutter underwater using a diver powered pump and to determine if the cutter could cut materials other than wire rope. Cutting tests were performed in the diving tank.

Performance data for the hydraulic cutter is shown in Table V. The range of values and their mean are presented where applicable.

Table V. Wire Rope Cutter Data

Material Cut	Number of Tests	Time to Rig Cutter (min.)		Cutting Time (min.)		Number of Pump Strokes		Maximum Hydraulic Pressure (psi)
		Mean	Range	Mean	Range	Mean	Range	
1/2" Steel Wire Rope 6x19 w/IWRC	4	0.5	0.4-0.6	0.5	0.4-0.6	29	27-30	2000
1" Steel Wire Rope 6x19 w/IWRC	4	0.5	0.5-0.7	1.2	0.8-1.9	42	30-54	3000
Angle Iron 3/4x 3/4x1/8	2	0.5	0.4-0.6	1.0	0.8-1.2	40	40-41	1800
5/8" dia. Steel Rebar	2	0.5	0.4-0.6	1.5	1.1-1.9	43	41-45	6200
1" dia. Marine Communication Cable w/Armor Braid	2	0.5	0.4-0.6	1.2	1.1-1.3	40	38-45	1800

Figure 19. Hydraulic Wire Rope Cutter

Figure 20. Diver Using Wire Rope Cutter

The cutting of wire rope under tension was simulated by cutting 20 inch-long pieces of 1/2 inch wire tensioned to 14,000 lbs. (The energy stored in this length of wire rope was insufficient to cause any whipping of the rope during cutting.) The only difference in cutting the wire rope tension was half as many (approximately 15) pump strokes were required as for the untensioned 1/2 inch dia. wire rope.

The hydraulic wire rope cutter has several desirable features. It may be operated remotely if the cable to be cut is under tension, it is compact, and the single hydraulic hose is easy to handle. The cutting performance of the hydraulic cutter was very good. The design of the cutter facilitates chip removal, and the cutter only jammed once in the entire test program. This occurred when a single wire of a one-inch diameter wire rope unlayed while it was being cut three inches from the end and prevented the return of the cutter blade to the retracted position. The wire was removed in the water with a pair of pliers.

The hydraulic wire rope cutter is essentially a cutting head attached to a large diameter single acting hydraulic cylinder (ram). Like the rams mentioned in the previous section, the cutter should be stored in the extended position. The cutter parts behind the cutting head and in front of the piston are exposed to salt water and should be coated with a non-seizing rust preventative compound. No maintenance was required on the wire rope cutter except for some internal cleaning after two months of intermittent submerged operation. The cutting capability was not affected.

The bar stock cutter in Figure 21 was included in the test program. This cutter is built to cut mild steel bar to 5/8 inch diameter and hard steel bar to 1/2 inch diameter. The purpose in testing this tool was to determine its underwater performance when used with the diver-powered pump. The testing consisted of a limited number of cuts on different materials. It was necessary for one diver to hold the bar stock cutter while another diver operated the pump. The results of these tests are shown in Table VI.

Table VI. Bar Stock Cutter Data

Material Cut	Number of Tests	Cutting Time Minutes		Number of Pump Strokes		Maximum Hydraulic Pressure
		Mean	Range	Mean	Range	
1/2" Steel Wire Rope 6x19 w/IWRC	2	*	-	-	-	-
Angle Iron 3/4x3/4x1/8	2	1.5	1.4-1.6	52	50-53	9500
5/8" Diameter Steel Rebar	2	0.6	0.5-0.6	25	23-26	3500

* Would not cut.

The bar stock cutter performed well when cutting the steel concrete reinforcing bar. It is not suitable for cutting wire rope and angle iron because of the configuration of the cutting head. It tends to smash these items without cutting them. The bar stock cutter is also a single-acting hydraulic cylinder and should be stored with the jaws closed.

OPEN CENTER HYDRAULIC EQUIPMENT

Hydraulic tools and equipment with an open center valve configuration require two hydraulic hoses. The hydraulic fluid flows from the power source to tool and back to the power source whenever the power source is operating. Actuating the tool trigger or handle blocks the fluid bypass at the tool and directs the fluid through the tool hydraulic motor.

Diesel-Driven Hydraulic Power Unit

The diesel-driven hydraulic unit (see Figure 22) used with the open-center hydraulic salvage tools was built at NCEL. This unit has a variable hydraulic output from two to ten gpm and develops a maximum pressure of 2000 psi. This type of unit is being evaluated for use with hydraulic tools at depths generally less than 300 feet. This hydraulic unit was used with an open-center cutter (2 gpm), a winch power handle (6.5 gpm), and a hacksaw (4 gpm) for the test program. The flow rate (gpm) to the tool is controlled by a bypass flow regulator. This method of flow control is preferable because a flow rate can be supplied to the tool when a minimum of hydraulic power is converted to heat. The hydraulic unit performed very well during the tool tests. A detailed description and evaluation of this unit will be included in a future NCEL publication on power sources.

Cutter

The open-center cutter shown in Figures 23 and 24 weighs 27 pounds in water. It is designed to operate at 1 to 3 gpm and at pressures to 1800 psig. This commercial tool was designed for underwater cutting of wire rope and bar stock.

The purpose of evaluating this cutter was to determine its performance and any diver handling problems. The underwater tests for this cutter consisted of cutting wire rope and other materials. The results of these tests are shown in Table VII.

Figure 21. Bar Stock Cutter

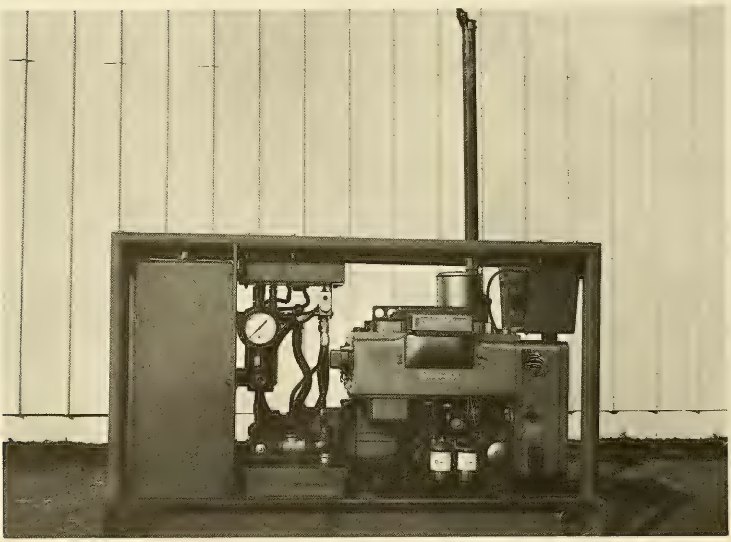

Figure 22. Diesel-Driven Hydraulic Power Unit

Figure 23. Open Center Cutter


Figure 24. Diver Using Open Center Cutter

Table VII. Open Center Cutter Data

Material Cut	Number of Tests	Cutting Time Minutes	
		Mean	Range
1/2" Steel Wire Rope 6x19 w/IWRC	8	0.1	0.1-0.2
Angle Iron 3/4x3/4x1/8	2	0.1	0.1
5/8" Diameter Steel Rebar	2	0.4	0.1-0.7
1" Diameter Marine Communication Cable w/Armor Braid	2	0.1	0.1

The weight of the cutter (27 pounds in water) made it difficult for the divers to operate for more than half an hour. The divers felt that if another handle was provided near the front of the cutter, it would be easier to hold. Because of the tool's weight the divers preferred to operate the cutter upside down (Figure 24) so that the material being cut helped to support the cutter.

The trigger of the open center cutter stuck repeatedly and the trigger guard is too close to the trigger, especially for a large gloved hand. However, these are minor problems which can be eliminated in a subsequent cutter.

This cutter was operated at 2-3 gpm and at a maximum pressure of 2000 psig during the test program. The pressure during cutting usually increased to 2000 psig, opening the hydraulic unit pressure relief valve. The cutter hydraulic circuitry performed reliably during the tests. However, the cutter head was not satisfactory. After several cuts, the female side of the cutting mechanism would often fill up with chips. The chip problem was especially severe when cutting materials other than wire rope. This cutter is being improved to eliminate the chip accumulation problem by reversing the configuration of the cutting mechanism.

Underwater Winch

A helicopter winch and a commercial hydraulic motor were modified to simulate a "disposable" winch system (Figure 25) for moving salvage material and equipment underwater. In a typical application inexpensive winches would be attached underwater at the major material handling areas. The winch lines would run through snatch blocks as required for moving heavy loads and equipment into position. A hydraulic power handle would enable one diver to operate any of the winches by mechanically coupling the power handle to any winch.

The helicopter winch housing contains a 40:1 worm and worm gear. The gears operate in pressure-compensated Mil-H-6083C hydraulic fluid.

The winch weighs 13 pounds in water, has a line capacity of 40 feet of 3/8 inch diameter nylon rope and has an average line speed of 20 fpm with 6.5 gpm through the power handle. The maximum recommended load for this winch is 500 pounds.

The power handle weighs 17 pounds in water. It was built utilizing a commercial hydraulic motor and a handle from another tool. The power handle motor can develop a torque of 460 inch-pound at 6.5 gpm and 1500 psi. The configuration of the power handle prevents any torque from being transmitted to the diver.

The objective of the test program was to demonstrate that divers could attach the winch system and move loads on the ocean floor. The test was conducted on the ocean floor at Anacapa Island. It consisted of bolting the winch to test stand, coupling the power handle to the winch, and moving 200 pounds (5.5 feet) of 2 inch chain across the bottom. The chain was first dragged about 30 feet across the ocean bottom to the pontoon. The variable buoyancy lift device in Figure 26 was then used to return the chain to its previous location. Subsequently, the chain and lift device were pulled to the pontoon while neutrally buoyant and then while positively buoyant. The underwater visibility was adequate for the divers to use hand signals between the winch operator and the rigger. The entire test went very smoothly and the "disposable" winch system appears to be a useful diver tool for salvage operations.

The winch and power handle were adequate for the test program. However, the design was compromised by the standard commercial components which were used. For Navy use it is preferable to have a winch with (1) a 1/2 to 1 ton pull capacity instead of 500 pounds, (2) a power handle weighing about ten pounds instead of 17 pounds, (3) a winch with three legs designed for easy attachment to flat or curved surfaces, (4) a non-stretching rope which will lay on the winch drum without line tension, and (5) a better mechanical connection between the power handle and winch, perhaps like the one in Figure 27.

Hacksaw

The hydraulic hacksaw in Figure 28 is commercially available. It is sold to cut railroad track for track repair and construction. The manufacturer claims that it can be used in a cutting machine or used as a hand tool. The hacksaw requires a hydraulic flow of 4 gpm and weighs 20 pounds in water.

The purpose in testing this tool was to determine if divers could use it to cut steel plate underwater. This saw was very difficult to operate on the surface and only a single attempt was made to operate it underwater.

The divers operated the saw in the guide track attached to a 1/2 inch thick steel plate (see Figure 28) and also hand held the tool against the plate without the track. It was not possible to cut with the saw in the track because the blade could not be forced into the

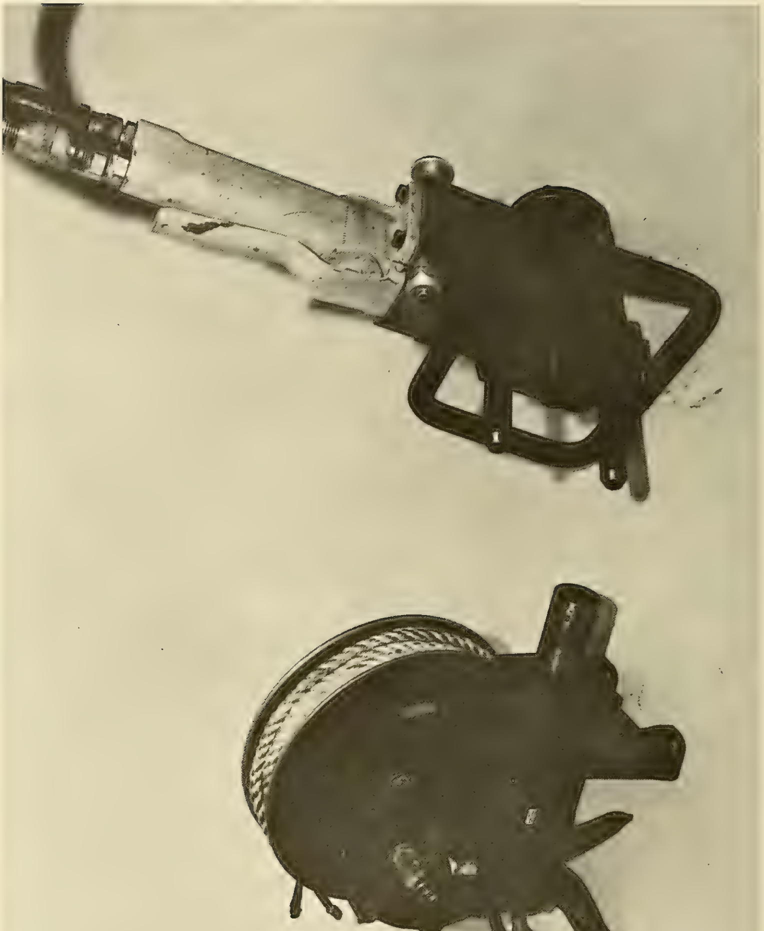

Figure 25. Winch and Power Handle

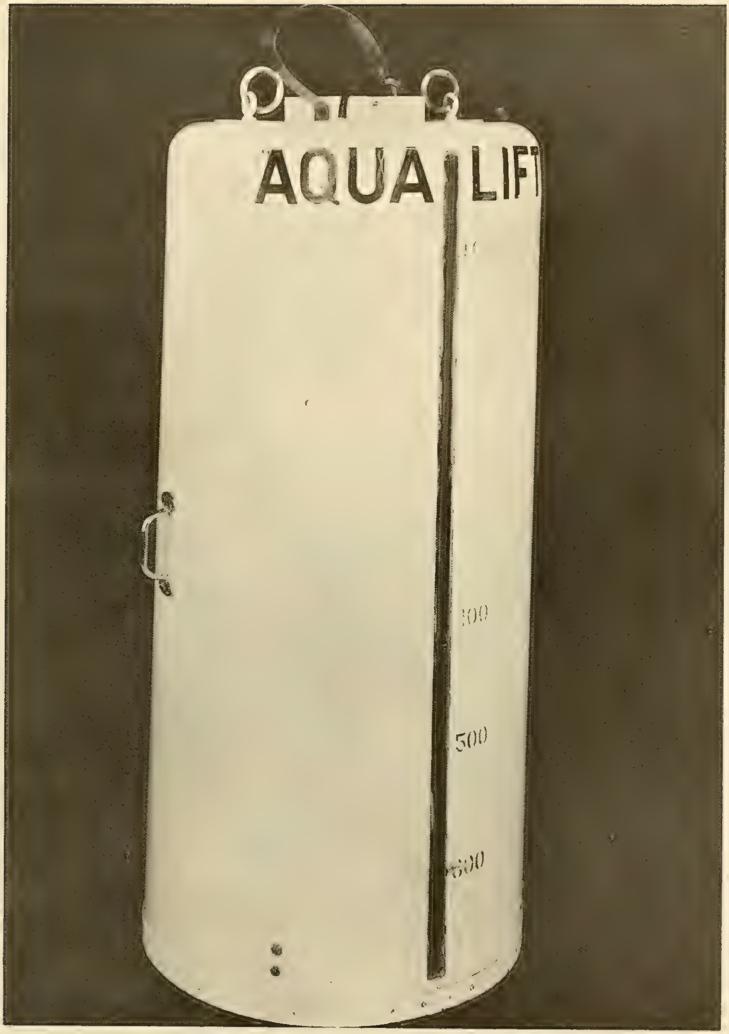

Figure 26. Variable Buoyancy Pontoon

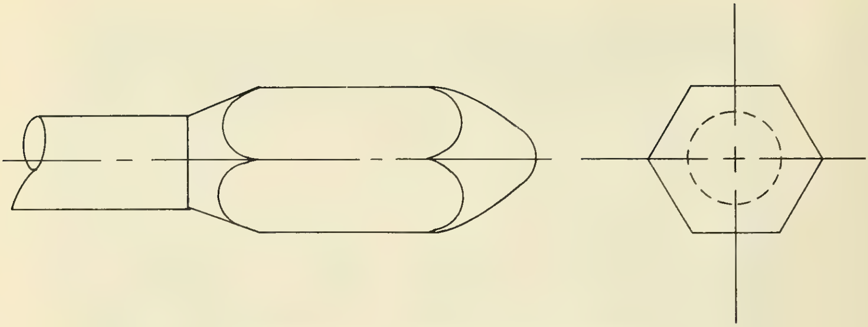

Figure 27. Suggested Winch Drive

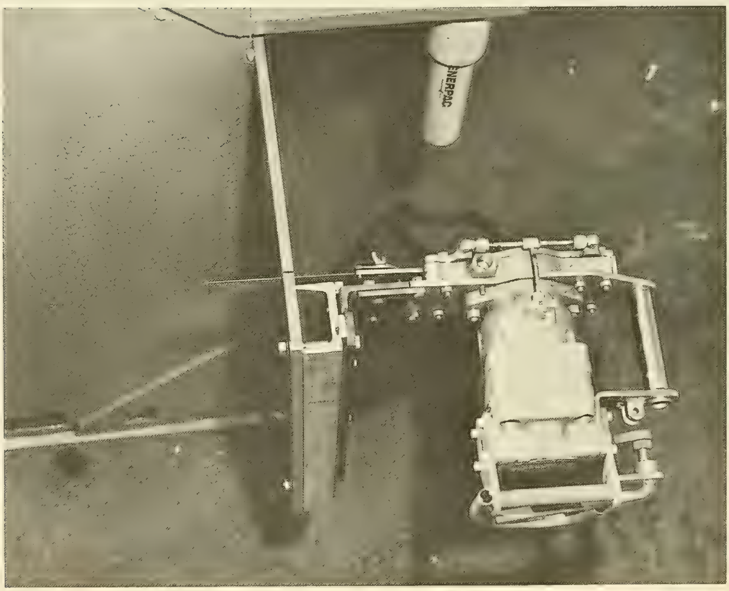

Figure 28. Hydraulic Hacksaw

steel. With the diver's hand holding the hacksaw, a 3/8 inch long cut was made in the 1/2 inch plate after 3 minutes of cutting.

Although the hydraulic hacksaw satisfactorily converts fluid power to a reciprocating motion, when the hacksaw is operated as a hand tool the diver cannot effectively load the blade. Another undersirable feature is that the hacksaw reciprocates instead of the blade unless it is forced against the steel plate being cut. The track (see Figure 28) designed to prevent the hacksaw from reciprocating, had the undesirable effect of making it even more difficult for the diver to force the blade into the work. This hacksaw is not suitable for use by divers in its present configuration. It is possible that this hacksaw can be adapted into a future cutting system where the diver is not required to hold the tool.

SUMMARY

Diver-Powered Equipment

Underwater tests at NCEL have determined the feasibility of using diver-powered hydraulic equipment for underwater salvage operations. This hydraulic equipment is commercially available and requires only nominal modifications and simple maintenance for reliable underwater operation. However, it cannot be overemphasized that utilizing the diver as a prime mover is justifiable only for small tasks and in emergency situations. For repetitive underwater work tasks the diver must be utilized as a tool operator and not as a prime mover. Using the diver as the prime mover on a large task may tire him so that his safety is jeopardized.

A modified two-stage hydraulic pump was used to convert the diver's energy to hydraulic power. With this type of pump, a diver can be expected to generate fluid power to operate small rams, hydraulic cylinders and cutters. The hydraulic rams and cylinders are limited to approximately a two-inch internal diameter with a 10 to 12 inch stroke to keep the pumping cycle less than five minutes and to permit easy diver handling of the components.

Open Center Equipment

Three open center hydraulic salvage tools were evaluated - a cutter, a power handle driven winch, and a hacksaw. None of these tools is recommended for Navy use in its present form. The cutter promises to be a very useful tool when the cutting mechanism is improved. It also would be advantageous to reduce the tool weight. The "disposable" winch and power handle concept appears to be promising for extensive underwater salvage operations. The hydraulic hacksaw is not a satisfactory diver tool in its present form.

CONCLUSIONS

1. Commercial hydraulic rigging and load handling equipment suitable for underwater use is limited to hydraulic ram and cylinders. These are relatively inexpensive due to their simplicity and wide-spread surface use. There is no commercially available open center hydraulic load handling equipment that is light enough for divers to move underwater. New innovative hydraulic powered load handling equipment including "disposable" winches with hydraulic power handles and hydraulic powered chain pulling equipment are required for underwater salvage.

2. Hydraulic-actuated cutting equipment suitable for underwater operation is available for cutting wire rope to 1 1/8 inch diameter and for steel bars to about 3/4 inch diameter. Additional open center cutting tools are required. Presently a cable cutter is available but needs improvement to perform satisfactorily. There is no diver operable hydraulic equipment commercially available for cutting flat steel plate.

3. Diver powered hydraulic pumps can be used to supply up to 5 cubic inches per minute of 4000 psig hydraulic fluid for periods up to 20 minutes. The diver powered pump systems are relatively inexpensive, do not require surface support and can be moved underwater by the divers.

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13. ABSTRACT

Extending the U. S. Navy's underwater salvage capability will require improved diver-operated tools and equipment. The Naval Civil Engineering Laboratory (NCEL) is conducting a program to develop hydraulic hardware for future underwater salvage operations. Commercially available hydraulic pumps, rigging, load handling and cutting equipment have been evaluated at NCEL to determine characteristic diver performance and mechanical suitability for underwater operation. Manually operated hydraulic pumps were modified and pumped against a load cell to determine reasonable levels of diver exertion. Tests have shown that divers can be utilized as prime movers for small jobs and that some conventional surface hydraulic equipment can be used underwater for reasonable periods of time with a minimum of additional maintenance. Surface hydraulic equipment suitable for underwater operation includes manual pumps, rams, cylinders and several cutters. However, innovative new equipment is urgently required for underwater salvage, particularly for load handling.

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